April 28, 1881.

THE PRESIDENT in the Chair.

The Presents received were laid on the table and thanks ordered for them.

The following Papers were read :—

I. "The Influence of Stress and Strain on the Action of Physical Forces." By HERBERT TOMLINSON, B.A. Communicated by Professor W. GRYLLS ADAMS, M.A., F.R.S. Received April 5, 1881.

(Abstract.)

PART I.—ELASTICITY.

"*Young's Modulus.*"

The values of "Young's modulus" were determined for several metals by a method devised by Sir W. Thomson. According to this method wires of the same material and diameter are suspended in pairs about an inch apart from each other, and are attached by one extremity of each to the same support; the other extremities being fastened in the one case to a scale-pan, and in the other to the centre of a bar of wood or metal carrying constant equal weights at each end : the latter wire is provided with a scale and the former with an index of some sort, which being level with and close to the scale, serves to measure any alteration of length produced by weights placed in the pan.

In these particular experiments the wires were about thirty feet in length ; a scale divided into half-millimetres and a vernier reading to $\frac{1}{20}$th of a millimetre attached respectively to the two wires, served to measure the temporary alterations of length produced by loading or unloading. The vernier was forked so that, though capable of free up and down motion, it could not readily be dislodged sideways, and by using a compound microscope an alteration $= \frac{1}{100}$th of a millimetre in the length of the wire could be estimated.

A large number of experiments with different loads were made, and after a great many unsuccessful attempts to account for certain discrepancies which could not be explained away as errors of observation, the following facts were elicited :—

(1.) After a wire has suffered permanent extension, the temporary elongation which can be produced by any load becomes less as the

interval between the period of permanent extension and that of applying the load becomes greater.

(2.) This increase of elasticity is greater in proportion for large loads than for small ones.

(3.) The increase of elasticity takes place whether the wire be allowed to remain loaded or unloaded between the period of permanent extension and that of the testing for the elasticity.

(4.) The *rate of increase* of elasticity varies considerably with different metals; with some the maximum elasticity is apparently attained in a few minutes, and with others not till some days have elapsed, iron and steel being in this last respect very remarkable.

(5.) The elasticity can also be increased by heavily loading and unloading several times, the rate of increase diminishing with each loading and unloading.

(6.) A departure from "Hooke's law" more or less decided, always attends recent permanent extension even when the weights employed to test the elasticity do not exceed one-tenth of the breaking weight.

(7.) This departure is diminished very noticeably in the case of iron, and much less so in the case of other metals, by allowing the wire to rest for some time either loaded or unloaded; it is also diminished by repeated loading and unloading.

With aluminium and zinc both the maximum temporary increase of length caused by putting on weight, and the recovery on the removal of the load are attained only after several hours, if the weights employed be not very small.

With tin and lead the loads employed were so small, in order to avoid permanent set, that the values of "Young's modulus" obtained for these metals cannot be relied on within 2 per cent.

A small though decided departure from "Hooke's law" was found in all cases, and the experiments abundantly proved that this law can only hold good practically for much smaller loads than are usually employed in determining the value of "Young's modulus" from the method of static extension.

A discussion of Wertheim's* experiments on elasticity will be found in the paper, and it is there pointed out that a principal cause of the differences of the values of "Young's modulus," obtained by him from the method of static extension, and from longitudinal or transverse vibrations, is to be found in his manner of experimenting according to the first of these methods.

The effect of permanent extension on the value of "Young's modulus," was tried according to the direct method for iron and copper, and indirectly for most of the metals.

From both the direct and indirect methods results were obtained which showed :—

* "Ann. de Chem. et Phys.," tom. xii, 1844.

(1.) That, in all metals, provided the wire has not been kept heavily loaded for some time before testing, permanent extension produces decrease of elasticity, if the strain be not carried beyond a certain limit.

(2.) That, if the extension be carried beyond the above-mentioned limit, further permanent increase of length causes increase of elasticity.

(3.) That, in the case of iron, heavy loading for some time so increases the elasticity that, even when the extension would have caused diminution of elasticity without such continued loading, the latter will, if sufficient time be allowed, change this diminution into an increase; in the case of copper this is not so.

It was also observed that, with iron which has been very heavily loaded for some time, the ratio of the temporary elongation to the load producing it becomes less as the load employed becomes greater, until a certain limit, depending upon the extent of the previous heavy loading, has been reached; whereas, with the other metals, and with iron which has suffered permanent extension without allowing the load producing the extension to remain for any appreciable time on the wire, the elongation increases in a greater proportion than the load.

The behaviour of iron in this respect, as well as the fact that this metal does not, until many hours have elapsed, attain its maximum elasticity, after having undergone permanent elongation, is probably to be attributed to the great coercive force of the metal.

To a similar cause may also be assigned the well-known increase of portative power of a magnet which can be produced by gradual loading; and the great difference between the tenacity of iron when loaded by slow degrees, and when loaded quickly.*

One of the above-mentioned indirect methods of determining the effect of permanent extension on the elasticity consisted in combining torsion with traction. The wire to be examined, some 95 centims. in length, passed through a small hole in a stout table, and was clamped at its upper extremity into a brass block, the latter resting on the table, and being sufficiently secured by a heavy weight placed on the top of it. Near the lower extremity, which was looped to receive a scale-pan, was clamped a second small brass block, to one end of which was attached a light mirror; the latter used in connexion with a scale and lamp enabled the observer to detect very small changes of torsion. The wire having previously received a certain amount of permanent torsion was loaded and unloaded several times with different weights, and the amount of temporary twist or untwist produced thereby determined.

* See J. T. Bottomley's experiments, "Proc. Roy. Soc.," vol. 29, p. 221.

The effect of suddenly chilling steel heated to a high temperature was found to be similar to that of excessive permanent extension of iron; and in general, it was concluded to be highly probable that whether the distance between the molecules be increased by mechanical strain or by the strain caused by sudden cooling, the elasticity in the direction of the line of separation of the molecules diminishes to a minimum as the separation increases, and then begins to increase.

Moreover, it would appear from the results which will be described in the other parts of this paper, that most, if not all, the physical properties of a substance are affected in a similar manner by stress and strain; whether these latter be the result of mechanical or of *any physical* agency.

Torsional Rigidity.

The torsional rigidity of the wires was determined by the method of vibrations. The vibrators were similar to those employed by Sir W. Thomson in his experiments on the rigidity and viscosity of metals,* namely, thin cylinders of sheet brass, supported by a thin, flat, rectangular bar. The wire to be tested passed perpendicularly through a hole in the middle of the bar, and was there soldered; the other end of the wire was then soldered into a stout iron bar, firmly held in a vice attached to a rigid support.

Great difficulty was experienced in making good observations of the rigidity of zinc, tin, and lead, in consequence of their great viscosity.

Several experiments were made to test the effect of permanent torsion and permanent extension on the modulus of rigidity.

From these experiments was concluded:—

(1.) That the loss of rigidity produced by twisting or stretching a wire beyond the limits of elasticity is partly diminished by rest.

(2.) That the loss is more sensible with large arcs of vibration than with small ones.

(3.) That the influence of rest is more apparent in the case of large vibrations than in that of small ones.

(4.) That continual vibrating through large arcs has a similar effect on the rigidity to that produced on the longitudinal elasticity by heavily loading and unloading. And—

(5.) That in the case of hard steel the effect of vibrating through a large arc for several minutes makes temporarily the rigidity as determined from such vibrations greater than that determined from smaller vibrations.

From the values of the torsional rigidity and "Young's modulus" were calculated the ratios of lateral contraction to elongation for the different metals, the formula used for this purpose being $\sigma = \frac{e}{2r} - 1$, in

* "Proc. Roy. Soc.," vol. 14, p. 289.

which e="Young's modulus," r=rigidity, both in grams per square centimetre, and σ=the required ratio.

In the following table are given the values of e, r, and σ for most of the annealed metals:—

Name of metal.	"Young's modulus." e.	Torsional rigidity. r.	Ratio of lateral contraction to elongation. σ.
Iron	1981×10^6	$773 \cdot 1 \times 10^6$	·281
Platinum	1490	692 ·7	·076
German silver	1335	493 ·7	·354
Copper	1160	440 ·6	·315
Platinum-silver	1051	369 ·9	·420
Zinc	767	338 ·4	·133
Silver	742	271 ·8	·367
Aluminium	673	265 ·2	·269
Tin	277	120 ·9	·145
Lead	167	74 ·0	·136

The mean value of σ for the *different* substances employed in the annealed condition =·2515, a number closely according with that assigned by Poisson from mathematical considerations, as the value of σ for *each*.

The metals copper, platinum, aluminium, silver, and platinum-silver were obtained from Messrs. Johnson, Matthey, and Co., as chemically pure, and the zinc, lead, and tin wires as being as pure as could be got from the ordinary process of distillation.

Experiments on the permanent alteration of density which can be produced by longitudinal traction proved, as the investigations of Wertheim and Thomson have already shown, that such alteration is very slight. In these particular experiments no change amounting to $\frac{1}{2}$ per cent. was detected, though the wires were strained to breaking.

Certain calculations were made to verify Wertheim's formula $e \times \alpha^7$=a constant, where e="Young's modulus," and α=the mean distance between one molecule and another, and it was found that this formula was approximately true. Moreover, the products of r and α^7 were calculated and found to be approximately constant for the different metals.

The influence of an electric current and of magnetism on the torsional rigidity of metals was also investigated, and the following results arrived at:—

(1.) The torsional rigidity of copper and iron is temporarily decreased by the passage of a powerful electric current, but is very little, if at all appreciably, altered by currents of moderate intensity.

(2.) The torsional rigidity of iron is temporarily diminished to a small but perceptible extent by a high magnetising force.

(3.) The effects mentioned in (1) and (2) are independent of any changes produced by the current in the temperature of the wire.

Finally, certain critical points are alluded to, there being at least two such for each metal, at which sudden changes take place in the ratio of the permanent extension produced by any load and the load itself.

The existence of the first of these critical points seems to prove beyond a doubt that, in all well-annealed metals, there is a true limit of elasticity, which is intimately connected with the elasticity of the substance, and it will appear from the investigations made in the other parts of this paper, that changes more or less profound take place in most, if not all, of the physical properties of the substance at these points.

II. "Lucifer: a Study in Morphology." By W. K. Brooks, Associate in Biology and Director of the Chesapeake Zoological Laboratory of the Johns Hopkins University, Baltimore, Md., U.S.A. Communicated by Professor Huxley, Sec. R.S. Received April 6, 1881.

(Abstract.)

Our knowledge of the life-history of this extremely interesting genus is very scanty, and the only published observations are contained in a short paper, without illustrations, in "Proc. Roy. Soc.," vol. 24, p. 132, by Willemöes-Suhm.

The death of this naturalist, only a few months after his paper was written, put an end to his studies, which he had expressed a hope of finishing, and I therefore take pleasure in stating that I have been so fortunate as to procure the eggs of *Lucifer*, and to trace every stage of the metamorphosis, from the time the larva leaves the egg up to the mature male, by the actual moulting of isolated specimens in captivity; and I have also been able to add a few observations upon its embryology.

The early stages of development are extremely interesting, since the segmentation is quite different from that of any arthropod egg which has been described. The egg undergoes total regular segmentation; there is a true central segmentation cavity, and during the early stages there is nothing to represent the yolk-pyramids of the ordinary crustacean egg. When segmentation is somewhat advanced, the granular matter becomes restricted to one of the spherules; this then pushes into the segmentation cavity, and appears to correspond to a single yolk-pyramid. Its outer end splits off as a blastoderm cell,